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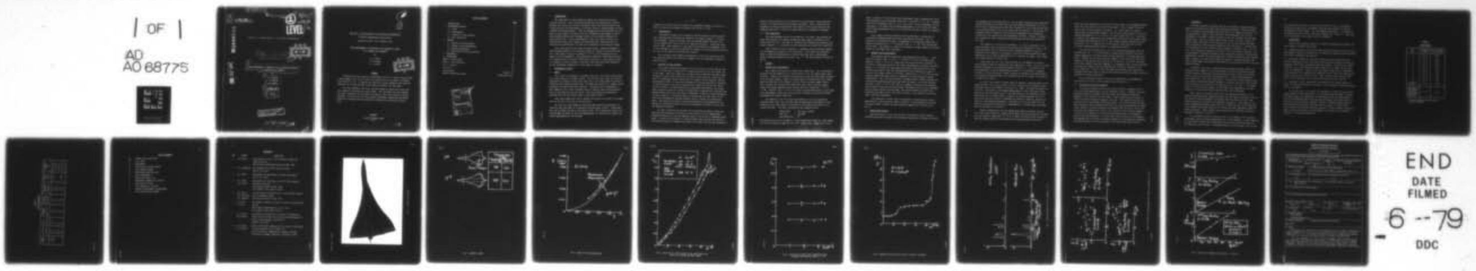

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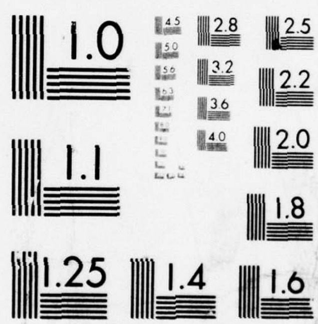

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SUMMARY

Buffeting tests were made on an aeroelastic model of a slender wing aircraft at Mach numbers of 0.2 and 0.3 and at low densities, over an angle of incidence range from 0° to 24°. In general the wing-root strains resembled those measured previously on an ordinary wind-tunnel model with almost the same shape.

The total damping in the first and third symmetric modes was derived from tape records of the wing-root strain signal. For both modes the total damping was almost independent of the angle of incidence, even in the region of vortex breakdown. For the first mode the measured aerodynamic damping was reasonably predicted by assuming that the model was a slender delta wing with attached flow.

LIST OF CONTENTS

1 INTRODUCTION

The advantages of using aeroelastic models for buffeting tests were reviewed recently[1]. Once a particular design has been selected the aircraft designer may require more precise information about the buffeting than he has already acquired from measurements of unsteady wing-root bending moment on stiff (ordinary) wind-tunnel models. Thus the designer may be concerned with the response in other modes of vibration than the fundamental wing bending, *eg* tail-plane bending combined with fuselage torsion, or the lateral vibration of a pylon mounted store. Direct measurements of this type cannot be made on an ordinary wind-tunnel model because the mode shapes and frequencies are not sufficiently representative, but they can be measured on an aeroelastic model.

These advantages have now been evaluated during a limited programme of buffeting measurements on an aeroelastic model of a slender wing aircraft made over a wide range of angle of incidence ($\alpha = 0^{\circ}$ to 24°) extending into the region of vortex breakdown[2]. The measurements complement those made previously on a nominally identical model[3] (which were restricted to a much smaller range of incidence) and were intended to establish the buffet excitation parameter[4] and the aerodynamic damping over a wide range of incidence.

2 EXPERIMENTAL DETAILS

2.1 Model

Fig 1 shows a photograph of the model, which is a 1/55 scale flutter model of an early supersonic transport design. The aircraft skin, spars and ribs are represented by internal etching from light alloy; the volume within the model is stabilised with expanded plastic foam. The model was mounted on a support incorporating an internal normal force balance. The support also incorporated a small magnetic coil so that the model could be vibrated easily during wind-off tests in the laboratory and the tunnel. Thus this support was appreciably different from the two balances used in the previous tests[3].

Wire strain gauges were used to measure the strain on the skin of the model near the tip and at the root of the port wing.

The first and third symmetric distortion modes previously measured on a nominally identical model on a different sting are shown in Fig 2. These modes were quite strongly excited in the present tests. Fig 3 shows that close to the trailing edge the shape of the first bending mode (at 120 Hz in the tunnel) was closely approximated by the relation

$$y = An^2 ,$$

assumed in the theory used to estimate the aerodynamic damping in section 3.3. With the wind-on the frequency increased from 120 Hz to 124 Hz.

2.2 Measurements

The limits of normal force rigorously enforced during the earlier tests[3] were relaxed because the model had completed its original purpose - a flutter test programme. During the present tests the maximum normal force was 333 N (75 lb) compared with only 102 N (23 lb) applied previously. During the tests several small cracks appeared in the plastic foam forming the aerodynamic lines of the fuselage, but there were probably no changes in the load bearing structure, for none of the measured wing modes were altered.

The unsteady strain signals were measured on line with a Bruël and Kjaer 2107 spectrum analyser and recorded on magnetic tape for subsequent analysis as detailed below.

2.3 Analysis of wing response

The response signals were generally at a low level on replay from the tape (5 to 35 mV rms) with a significant dc component present due to the steady lift on the model. Hence the signal was ac coupled into an amplifier and then passed through a low pass filter which was 3 dB down at 400 Hz and had a final cut off rate of 60 dB/decade, before being input to a digital Fourier analyser (Hewlett Packard model 5451B). As there was a minimum of 20 seconds duration of recording of random response at each test condition this length of data was used, split into 20 records of 1 second duration each containing 4096 samples. An average power spectrum of these 20 records was formed after weighting each block with the Hanning window and it was then Fourier transformed to produce an autocorrelogram. The block length of 1 second was chosen to ensure that the final value of the valid autocorrelogram at maximum available lag (0.5 second) was sufficiently small. The positive lag half of the autocorrelogram was then weighted with an appropriate exponential window and Fourier transformed to produce a vector plot for subsequent analysis[5].

In order to indicate the accuracy of this analysis procedure a check was made using data generated by driving a filter with a Q of 50 (representing a mechanical system of 1% critical damping) tuned to 271 Hz with a broadband random input. Ten sets of 20 records of 1 second duration were acquired for analysis. The system frequency and damping were known to be stable over the data acquisition

period so that variability in the results is an indication of the statistical scatter to be expected with this analysis procedure. Table 1 shows that the frequency is closely determined but that there is fairly wide scatter in the damping values (0.8 to 1.2%) for a system which is of nominally 1% damping.

2.4 Test conditions

The closed working section of the RAE 3ft × 3ft tunnel was selected for these tests because its quadrant allowed the model angle of indicence to be varied from 0^{o} to 25^{o}. The angle of incidence was progressively reduced as the kinetic pressure, q , increased to avoid exceeding the normal force limitation.

Table 2 gives the test conditions. A roughness band of ballotini spheres 0.25 mm diameter was applied to fix transition. Scale effects are generally small on buffeting measurements on slender wings with sharp leading edges, except at Reynolds numbers below about R_{C_O} 1×10^{6} (see discussion of Fig 10a, Ref 4).

3 RESULTS

3.1 Normal force measurements

Fig 4 shows the variation of normal force coefficient, C_N , with angle of incidence for Mach numbers of M = 0.20 and 0.30 at the two lowest tunnel total pressures. These total pressures were selected to give the same kinetic pressure at the two Mach numbers. Hence at a given angle of incidence the static loads should be identical in the absence of scale effects and Mach number effects. Fig 4 confirms that between these conditions scale effects and Mach number effects are indeed negligible over the wide incidence range from $\alpha = 4^{o}$ to $\alpha = 18^{o}$. However, from $\alpha = 19^{o}$ to 24^{o} there are large differences in the normal force measurements, which were very unsteady, although the wing rms buffeting measurements were almost identical.

For comparison with the present measurements on the early supersonic transport model, Fig 4 also includes some for unpublished measurements of the normal force on a much larger, stiff model of the production version of the Concorde aircraft. The model configuration was designated thus:

leading edge - type BA_O (rounded)
wing tips - type EOT
nose deflection - 0^{o}.

This model was tested in the RAE 13 × 9ft low speed wind tunnel at a Mach number of 0.25 and a Reynolds number of 4.8×10^{6}. Apart from a change in zero lift

angle of about 1.5° these normal force measurements agree remarkably well with those measured on the aeroelastic model at $M = 0.20$ and $R = 1.5 \times 10^{6}$. Although this level of agreement with the C_N at the 'stall' (vortex breakdown) could be fortuitous, it is likely that buffeting measurements on this aeroelastic model would closely approximate those on the production aircraft, despite the geometric differences.

Fig 5 shows a further indication that the wing flow is insensitive to variations in Reynolds number and static aeroelastic distortion. The C_N measured on the aeroelastic model is independent of the Reynolds number over a range of incidence from $\alpha = 4^{\circ}$ (attached flow) to $\alpha = 10^{\circ}$ (fully established vortex flow). The comparison could not be extended to higher angles of incidence because of the normal force limitation.

3.2 Dynamic strain measurements

Fig 6 shows a typical variation of unsteady-wing-root strain, ε , with angle of incidence from $\alpha = 0^{\circ}$ to $\alpha = 24^{\circ}$ at $M = 0.3$ and the lowest total pressure. From $\alpha = 0^{\circ}$ to 4° we may infer that the wing flow is attached, for the level of buffeting excited by the tunnel unsteadiness is constant, and small. Between $\alpha = 6^{\circ}$ and 8° the wing response increases significantly and we know from previous tests[3,4] that this corresponds with the formation of a pair of vortices on the upper surface of the wing. However from $\alpha = 8^{\circ}$ to 18° the wing response remains virtually constant, although the vortex strength increases progressively. The resultant excitation probably remains constant because the vortices move progressively further away from the wings as the vortex strength increases. From $\alpha = 20^{\circ}$ to 24° there is a dramatic increase in the wing-root strain, which we know from previous tests[3] corresponds with the vortex breakdown point crossing the wing trailing edge. The vortex breakdown condition thus represents the upper limit of the flight envelope, in the absence of any drag-speed stability requirement.

It is important to notice that the character of these wing-root strain measurements on the aeroelastic model is similar to that measured on the stiff wind-tunnel model of almost the same planform (compare Fig 6 with Fig 10 of Ref 3).

3.3 Damping measurements

Spectral analysis of the tape records of the wing-root strain signals indicated significant responses at three model frequencies of interest for which

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the dampings were established (Fig 7). Two of these frequencies were identified without difficulty as the first and third wing bending frequencies (at 124 Hz and 272 Hz) corresponding quite well with the modes (at 120 Hz and 263 Hz) found in the ground resonance test in the tunnel with the wind-off. The increase in frequency (wind-on) compared to the wind-off measurements may be plausibly attributed to the presence of some aerodynamic stiffness. However, no significant variation in these frequencies with equivalent airspeed was measured at $M = 0.30$.

The response at 112 Hz was not expected. It was not identified in the ground resonance test and may have been confused with the mode at 124 Hz. (The spectrum analyser used in these tests had a minimum bandwidth of only 6%.) Tentatively this response is attributed to the force balance/aeroelastic model combination, and is thus unrepresentative of a response in flight. Fig 7 shows other support modes at 50 and 75 Hz.

Fig 8 shows, for $M = 0.20$, typical values for the damping (% critical) plotted against angle of incidence for the responses at 112 Hz, 124 Hz and 272 Hz, derived according to the method described in section 2.3. The scatter on all the measurements is rather disappointing, however, it is possible to suggest, as shown by the dotted curves, a small increase in damping at the higher angles of incidence corresponding with the increased slope of the normal force/angle of incidence curve (Fig 4).

In view of the scatter on these values of damping, a check was made on the system accuracy with a filter tuned to 271 Hz, excited with a broadband random electrical input, as described in section 2.3. Table 1 includes the results of this test. The scatter of the damping measurements is about the same as that measured in the wind tunnel tests at the same frequency and indicated in Fig 8. Hence there is no *a priori* reason to question the usual assumption that the excitation from the vortices is broadband and random in character, despite the scatter on the damping measurements. (The mode at 272 Hz was chosen for this exercise, because this mode was not contaminated by a closely spaced adjoining mode, as the mode at 124 Hz was.)

Careful examination of all the damping measurements (obtained for four out of five test conditions) showed that the most consistent values were obtained over the incidence range from $\alpha = 6^{o}$ to 9^{o}, while the vortices were rolling up from the leading edge and the buffeting was increasing rapidly (See Fig 6).

Hence for every combination of velocity (U) and density (ρ) the damping measurements over this range of incidence were averaged. These averaged values are then plotted in Fig 9 against the product, ρU, which should be linearly related with the aerodynamic damping. For the first bending mode at 124 Hz the damping measurements at M = 0.2 and 0.3 do vary linearly with ρU. The slope is close to that predicted by the attached flow theory for a delta wing of similar planform (see Appendix E, Ref 4). The residual damping, derived by extrapolation to $\rho U \equiv 0$, appears to be 0.8% critical, about the level of the structural damping measured wind-off at atmospheric pressure.

For the third bending mode at 272 Hz the damping measurements also vary linearly with ρU. It is not possible to make a good estimate of the aerodynamic damping for this mode because of the complexity of the mode shape (see Fig 2). However the residual structural damping is only about 0.2% critical, compared to the measured value wind-off of 1% critical. In view of the anomalies in the residual structural damping, it is suggested that in future the wind-off structural damping should be measured with the tunnel evacuated to low static pressures. A test of this type might also indicate some variation in frequency which would help to explain the difference between the wind-off/wind-on frequencies discussed previously.

For the unidentified mode at 112 Hz the damping must be predominately structural, for it only varies slightly with the product ρU.

3.4 The buffet excitation parameter

It had been intended to derive the buffet excitation parameter for the first and third bending modes as fully described in Ref 4. However, there were anomalies between the dynamic wing-root strain displacement calibrations measured in the laboratory and the tunnel. These calibrations were needed to define the buffet excitation parameter precisely. The anomalies could not be resolved without considerable additional effort. Even if this effort had been made available, precise agreement would not have been achieved because of significant changes in frequency between the laboratory and the tunnel, *eg* for the first mode the frequency was 110 Hz in the laboratory with the sting clamped to a surface table compared to 120 Hz with the sting attached to the quadrant. Despite these uncertainties, it could be seen from the level of the responses and dampings that the buffet excitation parameter for both modes was comparable with that measured for the first mode on a 65° delta wing (Fig 10a, Ref 4).

4 DISCUSSION

The tests described illustrate some of the problems of using aeroelastic models for buffeting tests which were discussed previously[1]. The main limitation is imposed by the somewhat arbitrary value of the maximum lift which it is considered safe to apply. More precisely, the maximum model lift would be determined by the model strength (relative to the real aircraft) and the model fatigue life. Even for a replica model (model stress = aircraft stress) the model fatigue life would be less than that of the aircraft because the model scale inevitably produces higher frequencies than the aircraft. In these tests it was essential to cover the full range of angle of incidence from $\alpha = 0^{\circ}$ to 24°. This requirement restricted the tests to very low kinetic pressures. The correspondingly low Reynolds numbers did not apparently influence the buffeting measurements, because the present model has a slender planform and sharp leading edges. However, on wings with low/moderate angles of leading edge sweep and round leading edges, appreciable scale effects would inevitably occur at such low Reynolds numbers.

In general, more time is required when preparing aeroelastic models for buffeting tests compared to the time required for ordinary wind-tunnel models. On the aeroelastic model many more modes may be excited, and are of potential interest, than on an ordinary wind-tunnel model, for which measurements are often restricted to the first wing bending. In particular, recent dynamic tests on a range of wind-tunnel models[6] designed to establish the correct static aeroelastic distortion on wings with low sweep back at $M = 0.75$ and $\alpha = 7^{\circ}$ suggest that, on a true aeroelastic model of this swept-wing configuration, the wing response in torsion would be more important than the wing bending.

Fig 8 shows the important result that the damping measurements on this slender wing display only a small variation with the angle of incidence, even in the region of vortex breakdown, and indicate that the effects of static and dynamic aeroelastic distortion are relatively unimportant. The scatter of the present damping measurements looks poor, but is about the same as that measured on an ordinary wind-tunnel model of a 65° delta wing with comparable lengths of buffeting signals. (Those signals were analysed by the random dec process as described in Appendix B of Ref 4.)

It is probable that more accurate values of the damping could be derived if the model could be excited harmonically at a fixed frequency. A small magnetic coil was provided within the present model for exciting the wind-off modes in the laboratory and the tunnel. Although adequate for this purpose, the coil was

not sufficiently powerful for tests with the wind-on, even at low angles of incidence and small kinetic pressures, when the model response to the flow unsteadiness was quite small. The total damping coefficient, ζ , appears in the expression for the buffet excitation parameter[4] as a term $\zeta^{\frac{1}{2}}$. Hence the accuracy achieved in the present tests is acceptable.

5 CONCLUSIONS

Tests on an aeroelastic model of a slender wing supersonic transport aircraft suggest three main conclusions.

(1) Aeroelastic models can be used successfully for buffeting tests over very wide ranges of angle of incidence, but the appropriate normal force limit should be carefully established and observed.

(2) Aeroelastic models can give more detailed response information than ordinary wind-tunnel models. Hence more time should be provided to prepare an aeroelastic model than an ordinary wind-tunnel model. In particular a careful 'wind-off' test on the aeroelastic model mounted on its support in the wind tunnel is recommended. Ideally, this test should be made both at atmospheric static pressure (for comparison with laboratory tests) and at the lowest static pressure used for the 'wind-on' tests. Both 'wind-off' tests are best made after a brief shake-down run to establish the modes excited 'wind-on'.

(3) Estimates of total damping can be obtained from the model response to either the flow unsteadiness in the tunnel or the excitation provided by separations on the model.

In view of these conclusions it is legitimate to regard the use of aeroelastic models for buffeting tests as a well established technique. Ordinary wind-tunnel models are appropriate for approximate buffeting measurements in the first wing-bending mode[7] during project development and may even give an indication of the torsional response[8]. However, aeroelastic models must be used for precise measurements when the aircraft design is finally frozen. Such buffeting tests should preferably be made on a large, complete aeroelastic model so that both symmetric and antisymmetric responses can be correctly evaluated, as discussed previously[7].

Table 1

SYSTEM CHECK

Test set	Frequency f (Hz)	Total damping (% critical)
1	271.6	0.92
2	271.2	0.95
3	271.2	0.82
4	271.1	0.79
5	271.2	0.96
6	271.0	0.96
7	271.2	1.13
8	271.1	0.99
9	271.4	1.03
10	271.4	1.22
Average of 1 to 10	271.2	0.98
Regarded as one single record of 200 seconds duration	271.2	0.97

Every set represents 20 records of 1 second duration

Table 2

TEST CONDITIONS

Mach number M	Total pressure (kN/m^2)	Total pressure (in Hg)	Reynolds number $R_{C_o}(\times 10^{-6})$	Kinetic pressure $q(kN/m^2)$	Free stream density $\rho(kg/m^3)$	Velocity ratio U/a^*	Incidence range (o)
0.20	59.3	17.5	1.5	1.6	0.71	0.218	0 to 24
0.30	27.1	8	0.9	1.6	0.32		0 to 24
	54.2	16	1.8	3.2	0.63		0 to 14
	81.3	24	2.7	4.8	0.94	0.326	0 to 10
	98.3	29	3.2	5.8	1.14		0 to 9

LIST OF SYMBOLS

C_N	normal force coefficient
C	root chord
M	Mach number
q	$\frac{1}{2}\rho U^2$ kinetic pressure (N/m^2)
R	unit Reynolds number
U	free stream velocity (m/s)
y	wing displacement
α	angle of incidence (o)
γ	aerodynamic damping (% critical)
ε	rms wing root strain
ζ	total damping (% critical)
η	spanwise displacement (% semi-span)
ρ	free stream density (kg/m^3)

REFERENCES

No.	Author	Title, etc
1	D.G. Mabey	Some remarks on the use of aeroelastic models for buffeting tests. RAE Technical Memorandum Structures 880 (1976)
2	N.C. Lambourne	The breakdown of certain types of vortex. ARC CP 915 (1965)
3	D.G. Mabey	Measurements of buffeting on slender wing models. ARC CP 917 (1967)
4	D.G. Mabey G.F. Butler	Measurements of buffeting on two 65° delta wings of different materials. RAE Technical Report 76009 (1976) *Also* AGARD CP 226, Paper 6 (1977)
5	K.H. Heron D.R. Gaukroger C.W. Skingle	The processing of response data to obtain modal frequencies and damping ratios. RAE Technical Report 74027 (1974)
6	G.F. Moss D. Pierce	The dynamic response of wings in torsion at high subsonic speeds. RAE Technical Memorandum Aero 1706 (1977) *Also* AGARD CP 226, Paper 4 (1977)
7	G.F. Butler G.R. Spavins	Preliminary evaluation of a technique for predicting buffet loads in flight from wind tunnel measurements on models of conventional construction. AGARD CP 204 (1976)
8	G.F. Butler G.R. Spavins	Wind tunnel/flight comparison of the levels of buffeting response intensity for the TACT F-111. Paper presented at Symposium on Transonic Aircraft Technology Programme, Lancaster, California (1978)

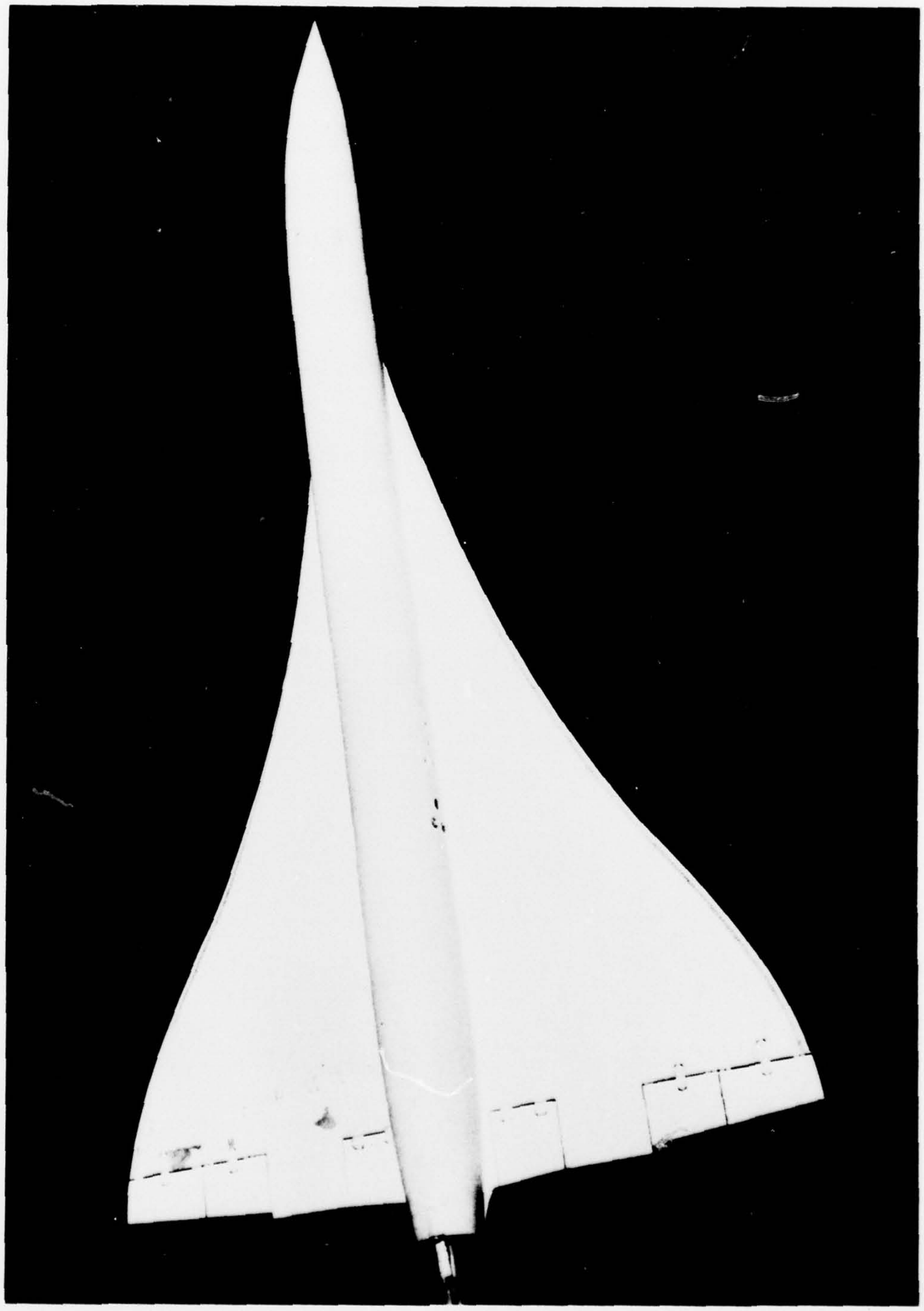
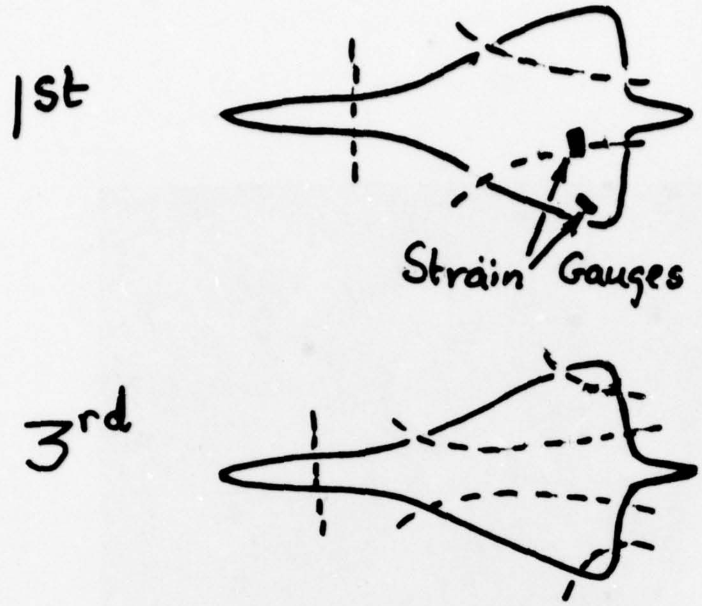


Fig 1 Slender wing model

Fig 2



Frequencies (Hz)	
Wind-Off	Wind-ON
120	124
263	272

Fig 2 Symmetric modes

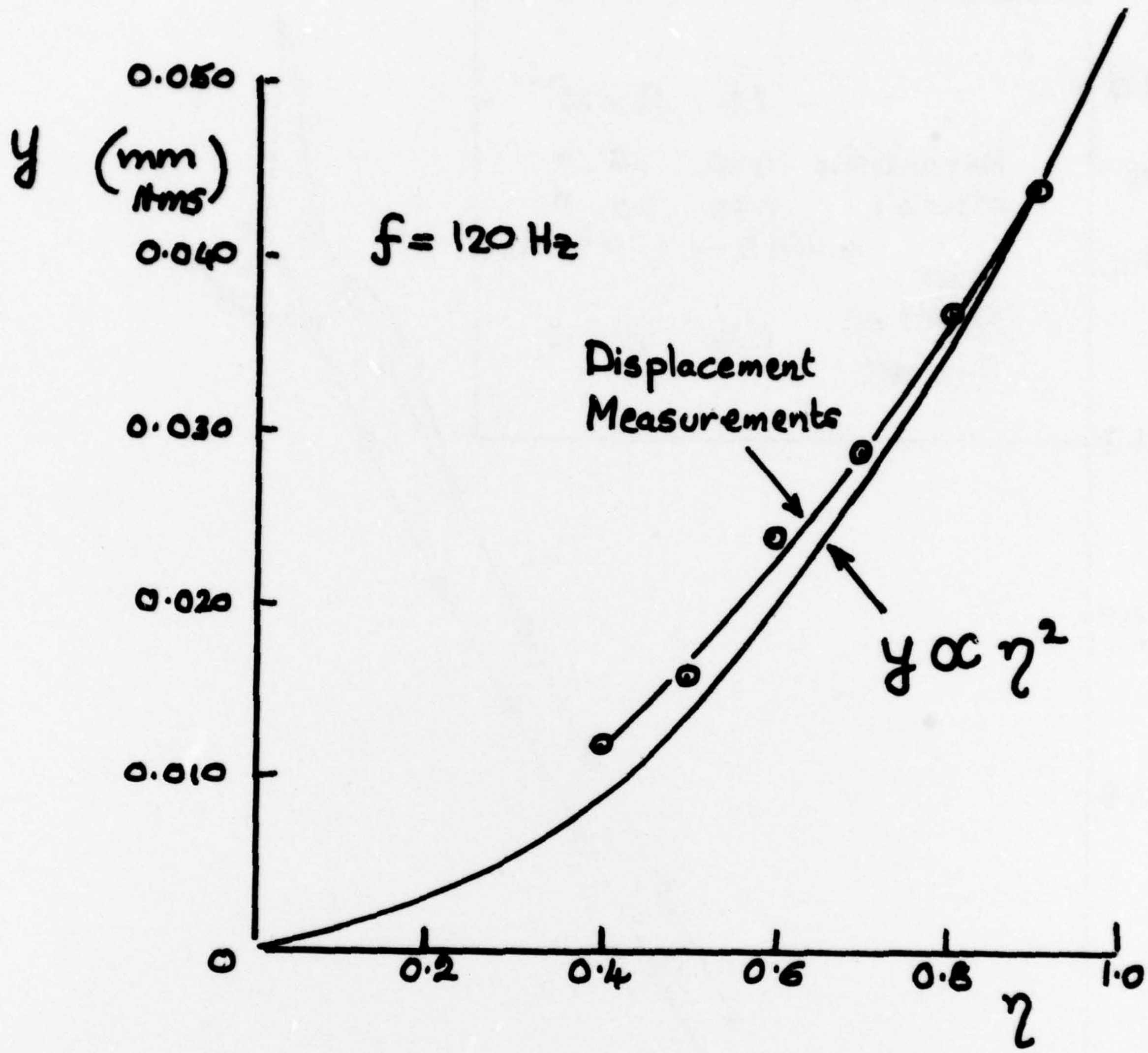


Fig 3 Shape of first bending mode

Fig 4

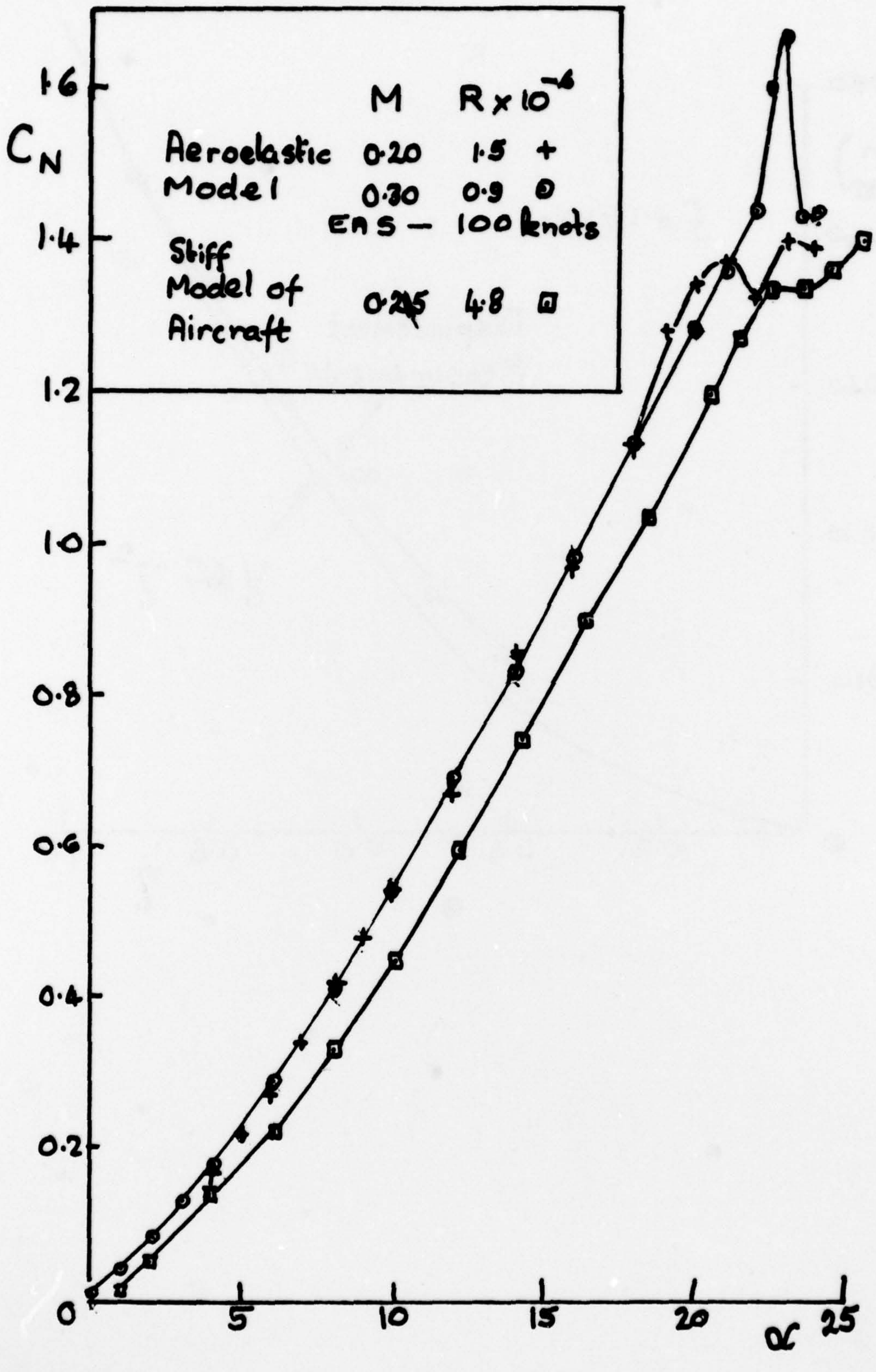


Fig 4 Variation of static normal force coefficient with angle of incidence and Mach number

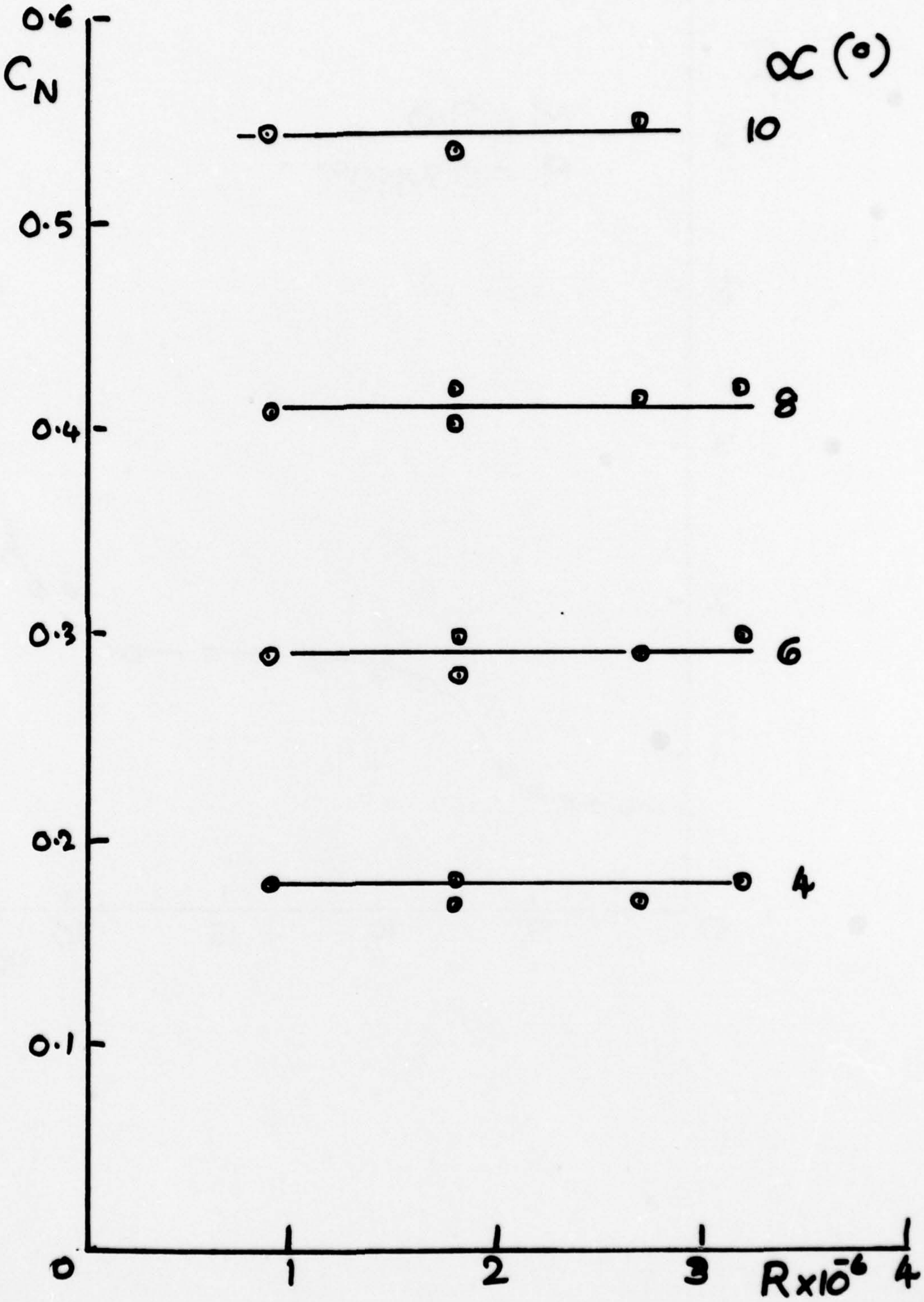


Fig 5 Variation of normal force coefficient with incidence and Reynolds number M = 0.30

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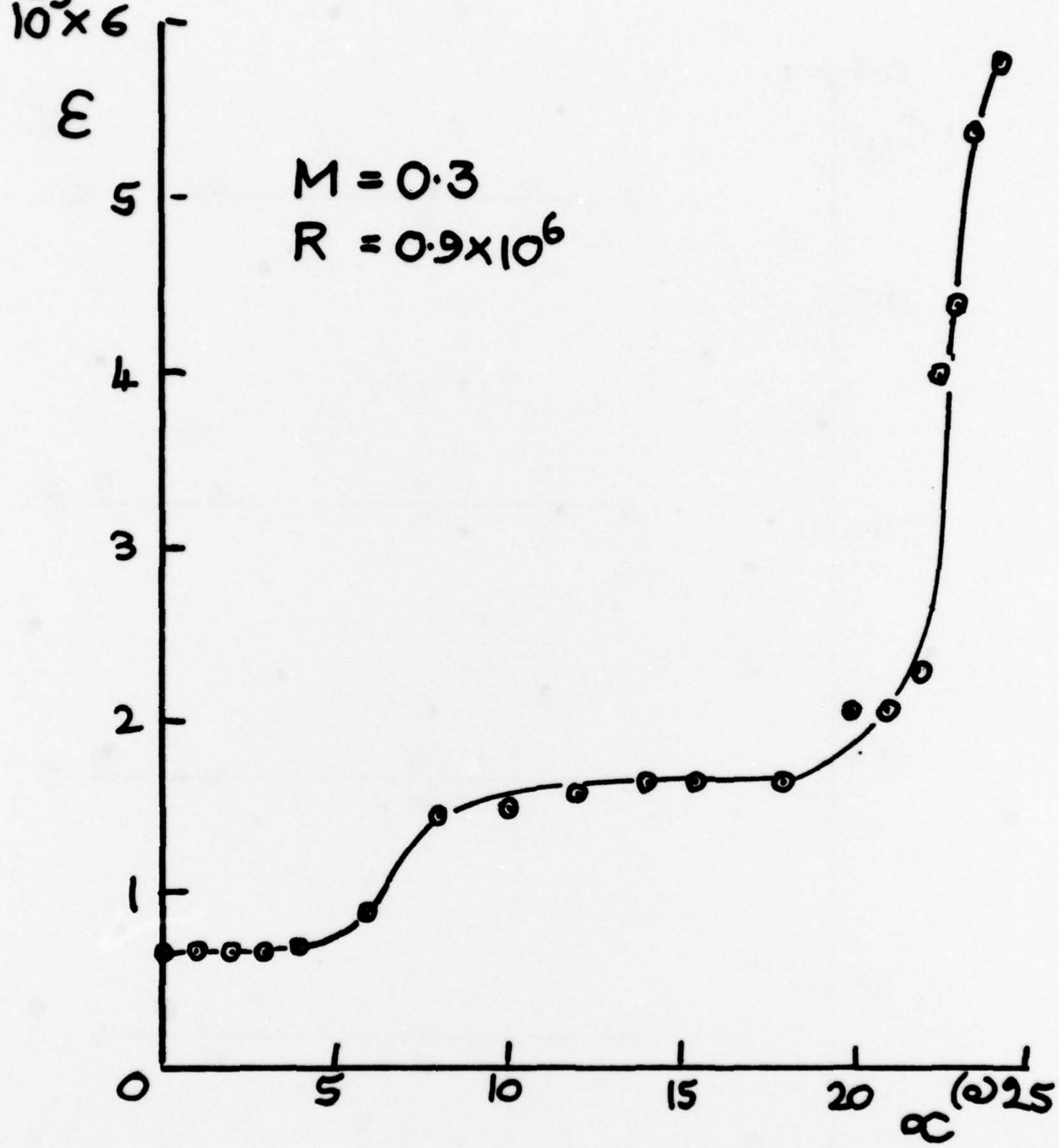

Fig 6 Unsteady wing-root strain (rms) v angle of incidence

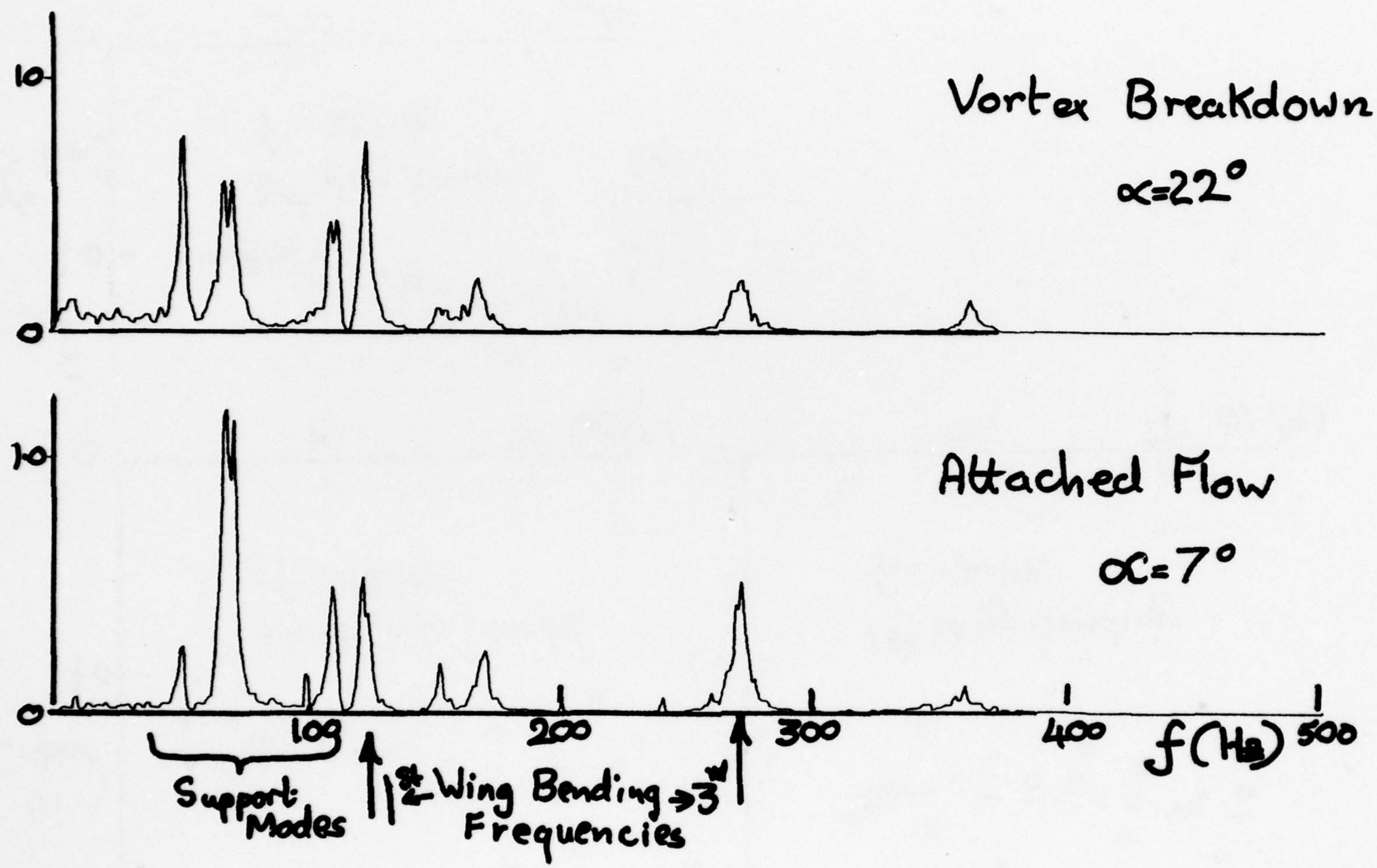

Fig 7 Typical spectra of strain signals M = 0.2

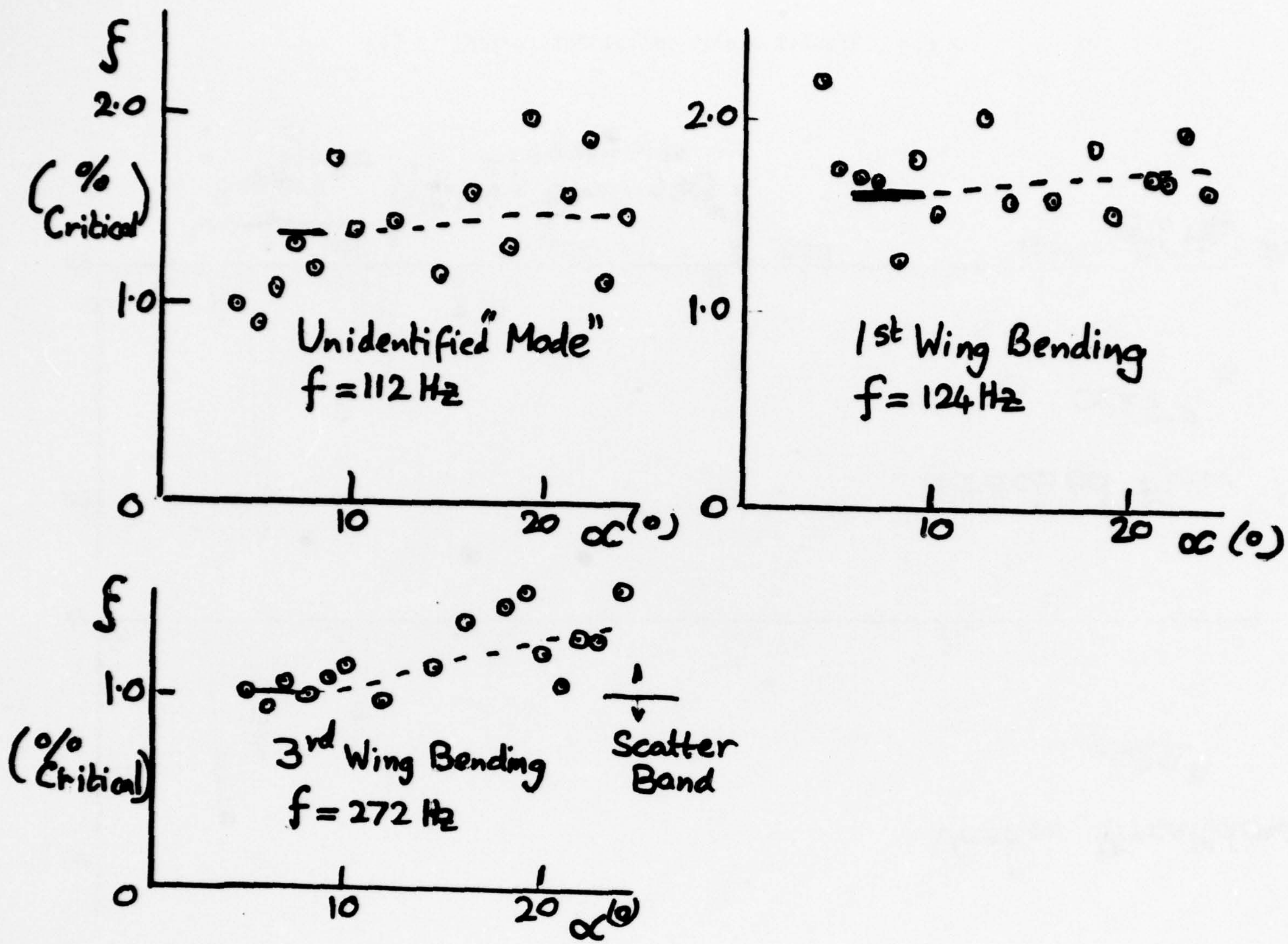

Fig 8 Variation of total damping with angle of incidence M = 0.20

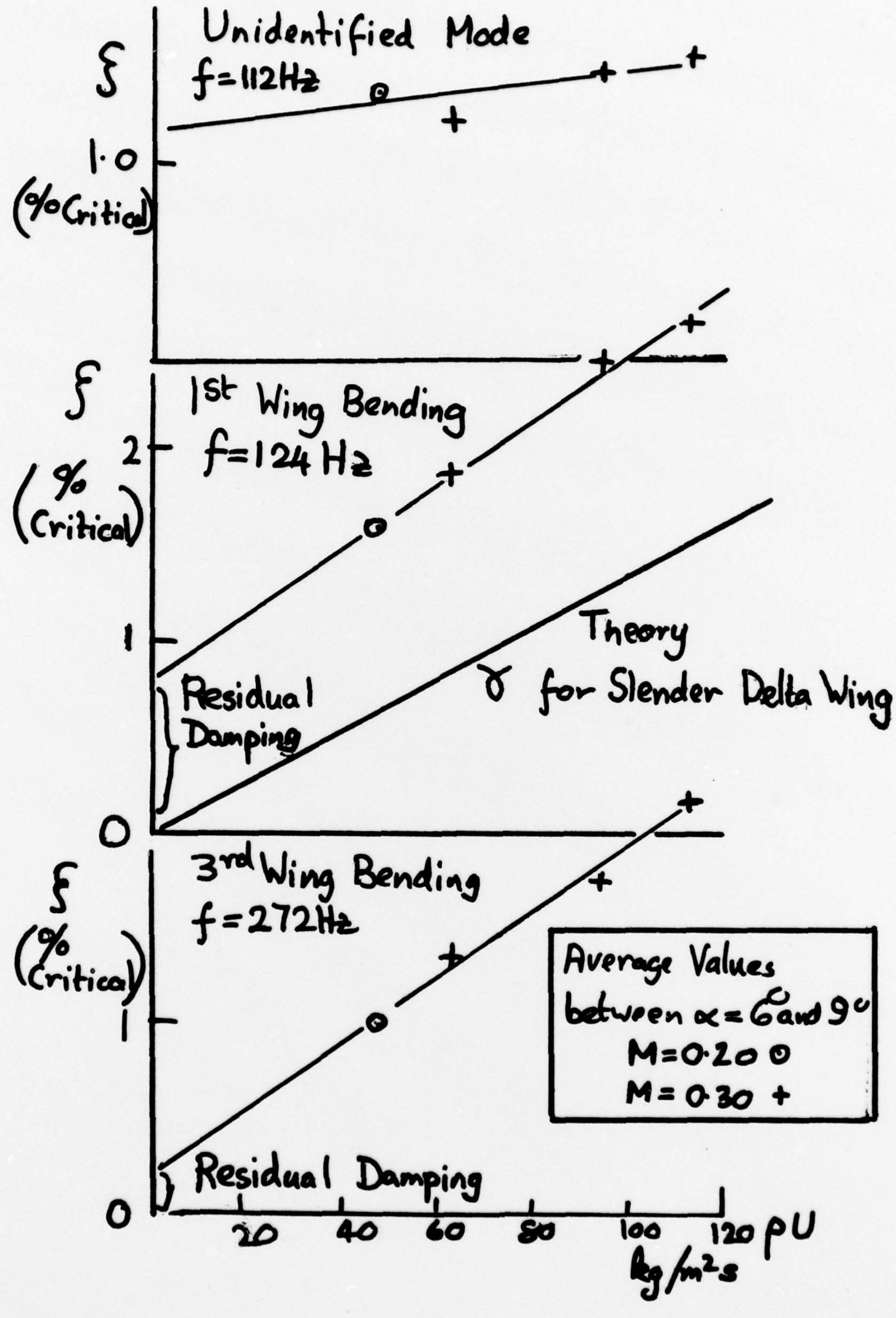

Fig 9 Variation of damping with (density × velocity)

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Buffeting.

17. Abstract

Buffeting tests were made on an aeroelastic model of a slender wing aircraft at Mach numbers of 0.2 and 0.3 and at low densities, over an angle of incidence range from 0° to 24°. In general the wing-root strains resembled those measured previously on an ordinary wind-tunnel model with almost the same shape.

The total damping in the first and third symmetric modes was derived from tape records of the wing-root strain signal. For both modes the total damping was almost independent of the angle of incidence, even in the region of vortex breakdown. For the first mode the measured aerodynamic damping was reasonably predicted by assuming that the model was a slender delta wing with attached flow.

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